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Design and Test Requirements for Space Flight Pressurized Systems

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This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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14. ABSTRACT

This Standard establishes the baseline requirements for the design, fabrication, assembly, installation, test, inspection, operation, and maintenance of pressure systems used in spacecraft and launch vehicles. This Standard is applicable to the procurement of pressurized hardware in space systems as a compliance document.

15. SUBJECT TERMS

Pressure systems, pressurized hardware, design requirements, test requirements, acceptance test, system test

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Change History

This document, TR-RS-2015-00005, is a revision of "Space Systems – Flight Pressurized Systems," TR-RS-2007-00005 originally released as TOR-2003(8583)-2896 Revision A.

Description of Change	Effective Date
• Revised titled to clarify scope • Clarified Section 1 in regard to scope and precedence with component requirements documents, AIAA S-080 and S-081 • References updated in Section 2 • Added definitions in Section 3 for clarity and removed unused terms • Changed format to line items for each requirement to improve clarity • Removed ground handling and ground service equipment requirements which are controlled by AFSPCMAN 91-710 • Separated system safety requirements to a new section, Section 6 • Revised wording of requirements on MEOP in Section 4.1 • Clarified handling of transient pressures in design and analyses in Section 4.2 • Revised contamination control requirements in Section 4.5 to achieve verifiable requirement text	26 November 2014

Foreword

This Recommended Standard by The Aerospace Corporation is an update to "Space Systems – Flight Pressurized Systems," TR-RS-2007-00005 originally released as TOR-2003(8583)-2896 Revision A. The Recommended Standard has as its origin all the requirements set forth for the flight pressurized systems in Section 4, General Design Requirements, and Section 6, Pressurized Systems Requirements, of MIL-STD-1522A, Standard General Requirements of Safe Design and Operation of Pressurized Missile and Space Systems. This latest revision clarifies requirements and purposely separates mission assurance requirements and system safety requirements.

It is the intent that this Recommended Standard be used together with the latest revisions of ANSI/AIAA S-080, Space Systems – Metallic Pressure Vessels, Pressurized Structures, and Pressure Components and S-081, Space Systems – Composite Overwrapped Pressure Vessels (COPVs) as compliance documents for the space flight pressure hardware in space system acquisitions.

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Contents

1. Introduction

1.1 Scope

This Recommended Standard establishes the baseline requirements for the design, fabrication, assembly, installation, test, inspection, operation, and maintenance of pressure systems used in spacecraft and launch vehicles. It deals primarily with the interfaces between the pressure vessel(s), or pressurized structures, and the corresponding pressure components within a specific pressure system; and interfaces between a pressure system and other spacecraft or launch vehicle systems. These requirements, when implemented on a specific pressure system, will assure a high level of confidence in achieving safe and reliable operation.

1.2 Application

This Recommended Standard is applicable to all pressure systems installed and operated in spacecraft, launch vehicles, and other space systems. Whereas this Recommended Standard pertains to the pressure system, the pressure vessels and/or pressurized structures and all associated pressure components that comprise the system are governed by the design and test requirements specified in References 7 and/or 8, as appropriate.

Note that pressure systems specifically excludes special pressurized equipment as defined in Reference 7 (e.g., heat pipes and batteries) and solid rocket motors cases which are controlled by Reference 9.

The requirements specified in this Recommended Standard may be tailored for specific programs with the approval of the appropriate approval authority. Tailoring of the requirements should be accompanied by a risk assessment per the process detailed in Reference 2 in order to remain compliant with Reference 2.

2. Referenced Documents

The following documents of the issue in effect on the date of invitation for bids or request for proposal form a part of this standard to the extent referenced herein.

1.	MIL-STD-202G	Test Method Standard Electronic and Electrical Component Parts
2.	MIL-STD-882E	Department of Defense Standard Practice, System Safety
3.	MIL-STD-1472	Military Standard, Human Engineering Design Criteria for Military Systems, Equipment, and Facilities
4.	MIL-E-6051	Electromagnetic Compatibility Requirements Systems
5.	MIL-S-8512	Support Equipment, Aeronautical, Special, General Specification for the Design of
6.	AFSPCMAN 91-710	Range Safety User Requirements Manual
7.	ANSI/AIAA S-080-1998	Space Systems – Metallic Pressure Vessels, Pressurized Structures, and Pressure Components
8.	ANSI/AIAA S-081A-2006	Space Systems – Composite Overwrapped Pressure Vessels (COPVs)
9.	TOR-2003(8583)-2895, Rev 1.	Solid Rocket Motor Case Design and Test (SMC-S-006)
10.	TR-RS-2014-00016	Test Requirements for Launch, Upper-Stage, and Space Vehicles (SMC-S-016-2014)
11.	DOT/FAA/AR-MMPDS-01	Metallic Materials Properties Development Standardization (MMPDS)
12.	CINDAS/USAF	Aerospace Structural Metals Handbook
13.	MIL-HDBK-17	Composite Materials Handbook
14.	TOR-2006(8583)-1	Configuration Management (SMC-S-002)
15.	SAE AS9100	Quality Systems - Aerospace - Model for Quality Assurance in Design, Development Production, Installation and Servicing

Unless otherwise indicated, copies of federal and military specifications, standards, and handbooks are available from Department of Defense Single Supply Point at http://quicksearch.dla.mil.

AIAA standards must be procured directly from the owner.

Aerospace TORs are available from the Aerospace Corporate Library. Requests, on official letterhead, should be addressed to:

The Aerospace Corporate Library
Mail Stop M1-199
P.O. Box 92957
Los Angeles, CA 90009-2957

3. Vocabulary

3.1 Abbreviations and Acronyms

COPV Composite Overwrapped Pressure Vessel

DSF Design Safety Factor

MEOP Maximum Expected Operating Pressure

MS Margin of Safety

NDI Nondestructive Inspection

NVR Non-volatile Residue

3.2 Definitions

The following definitions of significant terms are provided to ensure precision of meaning and consistency of usage. In the event of a conflict, the definitions listed here apply.

A-Basis Allowable: The mechanical strength or strain values such that 99% of the population will meet or exceed the specified values with a confidence level of 95%.

Acceptable Risk: The risk is a combination of the severity of the mishap and the probability that the mishap will occur. Acceptable risk refers to risk that the appropriate acceptance authority is willing to accept without additional mitigation.

Acceptance Tests: The required formal tests conducted on the flight hardware to ascertain that the materials, manufacturing processes, and workmanship meet specifications and that the hardware is acceptable for intended usage.

Applied Load (Stress): The actual load (stress) imposed on the pressurized hardware item in the service environment.

B-Basis Allowable: The mechanical strength values such that 90% of the population will meet or exceed the specified values with a 95% confidence level.

Burst Factor: The burst factor is a multiplying factor applied to the maximum expected operating pressure (MEOP) to obtain the design burst pressure.

Burst Pressure: The real pressure level at which rupture or unstable fracture of the pressurized hardware item occurs.

Component: A functional unit that is viewed as an entity for the purpose of analysis, manufacturing, maintenance, or recordkeeping.

Critical Condition: The most severe environmental condition for a particular failure mode in terms of loads, pressures and temperatures, or combination thereof imposed on systems, subsystems, and components during service life.

Damage-Tolerance Life (Safe-Life): The required period of time or number of cycles that the structure, containing the largest crack undetectable by NDI, is shown by analysis or testing to survive without leaking or failing catastrophically in the expected service load and environment.

Design Burst Pressure: A pressure that the pressurized hardware must withstand without rupture in the applicable operating environment. It is equal to the product of the maximum expected operating pressure (MEOP) and a design ultimate (burst) factor.

Design Safety Factor (DSF): A multiplying factor to be applied to limit loads and/or MEOP for purposes of analytical assessment and/or test verification of structural adequacy.

Detrimental Deformation: The structural deformation, deflection, or displacement that prevents any portion of the structure from performing its intended function, or that reduces the probability of successful completion of the mission.

Fatigue: The process of progressive localized permanent structural change occurring in a material subjected to conditions which produce fluctuating stresses and strains at some point or points and which may culminate in cracks or complete fracture after a sufficient number of fluctuations.

Fittings: Components of a pressurized system utilized to connect lines, other pressure components and/or pressure vessels within the system.

Flaw: A local discontinuity in a structural material, such as a scratch, notch, crack or void.

Hazard: A real or potential condition that could lead to an unplanned event or series of events (i.e. mishap) resulting in death, injury, occupational illness, damage to or loss of equipment or property, or damage to the environment.

Hazard Analysis: The analysis of systems to determine potential hazards and recommended actions to eliminate or control the hazards.

Hydrogen Embrittlement: A mechanical-environmental failure process that results from the initial presence or absorption of excessive amounts of hydrogen in metals, usually in combination with residual or applied tensile stresses.

Initial Flaw: A flaw or a crack-like defect in a structural material before the application of load and/or deleterious environment.

Limit Load: The maximum expected external load or combination of loads, that a structure may experience during the performance of specified missions in specified environments. When a statistical estimate is applicable, the limit load is that load not expected to be exceeded at 99% probability with 90% confidence.

Lines: Tubular pressure components of a pressurized system provided as a means for transferring fluids between components of the system.

Margin of Safety (MS): MS = Allowable Load/(Limit Load x DSF) – 1. Note that load may mean stress or strain.

Maximum Expected Operating Pressure (MEOP): The maximum pressure which the pressurized hardware is expected to experience during its service life in association with its applicable operating environments.

Mishap: An event or series of events resulting in unintentional death, injury, occupational illness, damage to or loss of equipment or property, or damage to the environment. For the purposes of this Standard, the term “mishap” includes negative environmental impacts from planned events.

Peak Transient Pressure: The maximum value of a pressure wave associated with the sudden opening or closing of a valve or with ignition, and that persists for only a fraction of a second.

Pressure Component: A component in a pressurized system, other than a pressure vessel, pressurized structure, or special pressurized equipment that is designed largely by the internal pressure. Examples are lines, fittings, gauges, valves, filters, bellows, and hoses.

Pressure Vessel: A container designed primarily for the storage of pressurized fluids and which

1) Contains stored energy of 14,240 ft-lb (19,310 joules) or greater, based on adiabatic expansion of a perfect gas; or

2) Contains gas or liquid which will create a mishap (accident) if released; or

3) Will experience a MEOP greater than 100 psi (700 kPa).

Special pressurized equipment such as batteries, sealed containers, heat pipes, and cryostats are not included.

Pressurized Structures: Structures designed to carry both internal pressure and vehicle structural loads. The main propellant tank of a launch vehicle is a typical example.

Pressurized System: A system that consists of pressure vessels, or pressurized structures, or both, and other pressure components such as lines, fittings, valves, and bellows that are exposed to and structurally designed largely by the acting pressure. Not included are electrical or other control devices required for system operation. Pressurized system is synonymous with pressure system. Note that in other documents such as Reference 10, the term “system” refers to the entire vehicle and “subsystem” refers to completed assemblies like propulsion. A propulsion subsystem per Reference 10 is termed a pressurized system within this document.

Proof Factor: A multiplying factor applied to the limit load or MEOP to obtain proof load or proof pressure for use in the acceptance testing.

Proof Pressure: The proof pressure is used to give evidence of satisfactory workmanship and material quality and/or establish maximum initial flaw sizes for damage-tolerance life (safe-life) demonstration. It is equal to the product of MEOP and a proof factor.

Qualification Tests: The required formal contractual tests used to demonstrate that the design, manufacturing, and assembly have resulted in hardware designs conforming to specification requirements.

Safety-critical: A term applied to a condition, event, operation, process, or item whose mishap severity consequence is either Catastrophic or Critical (e.g., safety-critical function, safety-critical path, and safety-critical component).

Safety-critical item: A hardware or software item that has been determined through analysis to potentially contribute to a hazard with Catastrophic or Critical mishap potential, or that may be implemented to mitigate a hazard with Catastrophic or Critical mishap potential. See Reference 2 for further description.

Scatter Factor: A factor applied to the estimated life of a structure to provide the certifiable life in fatigue analyses.

Service Life: The period of time (or cycles) starting with the manufacturing of the pressurized hardware and continuing through all acceptance testing, handling, storage, transportation, launch operations, orbital operations, refurbishment, retesting, reentry or recovery from orbit, and reuse that may be required or specified for the flight pressure system.

Special Pressurized Equipment: A piece of equipment that meets the pressure vessel definition, but which is not feasible or cost effective to comply with the requirements applicable to pressure vessels. Included are batteries, heat pipes, cryostats and sealed containers. See Reference 7 for further description and requirements.

Stress-Corrosion Cracking: A mechanical environmental induced failure process in which sustained tensile stress and chemical attack combine to initiate and propagate a crack or a crack–like flaw in a metal part.

System Safety: The application of engineering and management principles, criteria, and techniques to achieve acceptable risk within the constraints of operational effectiveness and suitability, time, and cost throughout all phases of the system life-cycle.

Ultimate Load: The product of the limit load and the ultimate design safety factor. It is the load that the structure must withstand without rupture or collapse in the expected operating environments.

4. General Requirements

This section presents general requirements for pressurized systems in terms of: (a) design, analysis, material selection and characterization, fabrication and process control; (b) quality assurance, operation and maintenance, including repair, and refurbishment; and, (c) storage. Additional detailed system requirements are presented in Section 5. Requirements specific to system safety are presented in Section 6.

4.1 System Analysis Requirements

4.1.1 System Pressure Analysis

MEOP is used as the baseline internal pressure necessary for test verification purposes. Each component within the pressurized system will have an MEOP. If a selected component is over-designed in terms of MEOP for the particular application, MEOP should still refer to the required application and a different term or qualifier should be used in referencing the over-designed capability.

As MEOP is determined at the system level, the unit requirements on MEOP in Reference 7 and 8 are superseded by the following more specific set of requirements.

[4.1.1-1] A thorough analysis shall be performed to establish the correct MEOP, leak rates, flow rates and other relevant performance parameters for all pressurized hardware within the pressurized system.

[4.1.1-2] For systems with zones operating at different pressures, the MEOP of pressure components and/or pressure vessels within each zone shall be determined. Examples of zones include portions of a system upstream and downstream of a pressure regulator and portions of a system isolatable by closure of a valve.

[4.1.1-3] MEOP shall include the variation of pressure with temperature during the service life in determining the maximum.

[4.1.1-4] MEOP shall include the system pressure rise allowed due to valve back pressure relief, regulator lockup behavior, and relief valve settings to include the tolerance of each of these parameters.

[4.1.1-5] MEOP shall include effect of vehicle acceleration.

[4.1.1-6] MEOP shall include the required fault tolerance aspects that affect maximum pressure. For example, single-fault tolerant systems with a pressure regulator must include the increased pressure provided by the redundant regulator stage lockup condition as the primary stage failure must be "tolerated" as part of the "expected" condition.

[4.1.1-7] The MEOP of pressure vessels and pressurized structures shall include the peak transient pressure incident on these units resulting from system operation. It should be noted that hydraulic transients typically have little amplitude within a pressure vessel.

[4.1.1-8] For pressure components, the proof pressure shall exceed the peak transient pressure arising in the component due to system operation such as valve actuation and water hammer. To be explicit, the pressure component MEOP need not include that portion of the peak transient pressure that

persists for only a fraction of a second. The ability of the hardware to withstand the transient condition without detrimental deformation is verified by the peak pressure being below the proof pressure level. For instances where the peak transient pressure falls below the product of the MEOP and the standard proof factor, this requirement is met with no added implementation requirements. For instances where the peak transient pressure would otherwise exceed the product of the MEOP and the standard proof factor, this requirement can be accomplished by either raising the MEOP value or by increasing the proof factor.

[4.1.1-9] For pressure components, the ratio of the design burst pressure to the proof pressure shall be greater than or equal to the ratio of the burst factor to the proof factor as specified in Reference 7's Table 2. If the proof factor was adjusted to accommodate peak transient pressures, this requirement can be accomplished by either raising the MEOP value or by increasing the burst factor.

4.1.2 System Analysis

[4.1.2-1] A detailed system functional analysis of the pressurized system shall be performed to determine that the operation, interaction, and sequencing of components within the pressurized system are capable of supporting all required actions.

Related system safety requirements are in Section 6.

[4.1.2-2] System analysis data shall show that:

a) The system provides the capability of maintaining pressure within MEOP in the event of interruption of any process or control sequence at any time during test or flight.

b) Redundant pressure relief devices have independent pressure escape routes during all stages of operation.

4.2 Structural Design Requirements

This section delineates the general design requirements for a pressurized system.

[4.2-1] The components of the pressurized system, including pressure vessels, pressurized structures, and pressure components, shall comply with Reference 7 (metallic hardware) and Reference 8 (composite hardware).

4.2.1 Loads, Pressures, and Environments

[4.2.1-1] The entire anticipated load-pressure-temperature history and associated environments throughout the service life of the pressurized system shall be determined in accordance with specified mission requirements.

[4.2.1-2] As a minimum, the following factors and their statistical variations shall be considered as appropriate:

a) The environmentally and operationally induced loads and pressures including transient pressure oscillations such as from water hammer.

b) The environments acting simultaneously with these loads and pressures with their proper relationships. Environments include temperatures and thermal gradients.

c) The frequency of application of these loads, pressures, environments, and their levels and duration.

[4.2.1-3] These data derived in [4.2.1-1] and [4.2.1-2] shall be used to define the design spectra used for both design analysis and testing.

[4.2.1-6] The design spectra shall be revised as the structural design develops and the loads analysis matures.

4.2.2 Strength

[4.2.2-1] All pressure hardware within the pressurized system including component interfaces, attachments, tie-downs, and other critical points shall possess sufficient strength to withstand limit loads, MEOP, and transient pressures in the expected operating environments throughout the service life without experiencing detrimental deformation.

[4.2.2-2] All pressurized hardware shall sustain system-level proof pressure without incurring gross yielding or detrimental deformation.

[4.2.2-3] All pressurized hardware shall also withstand ultimate loads (external loading) and design burst pressure (internal loading) in the expected operating environments without experiencing rupture or collapse.

Further strength requirements for pressure vessels, pressurized structures, and pressure components are in Reference 7 Section 4.2.2 and Reference 8 Section 5.2.2.

[4.2.2-4] The margin of safety shall be positive and shall be determined by analysis or test at design ultimate and design limit levels, when appropriate, at the temperatures expected for all critical conditions.

4.2.3 Stiffness

[4.2.3-1] The mounting and arranging of all components in the pressurized system and their stiffness effect on resonant response shall be factored into the design of the flight pressure system.

[4.2.3-2] The stiffness properties of the pressure system shall be such as to prevent all detrimental instabilities of coupled vibration modes, minimize detrimental effects of the loads and dynamics response that are associated with structural flexibility, and avoid detrimental deformation due to contact with other vehicle systems.

4.2.4 Thermal Effects

[4.2.4-1] Thermal effects, including heating and cooling rates, temperatures, thermal gradients, thermal stresses and deformations, and changes with temperature of the physical and mechanical properties of the material of construction, shall be factored into the design of the flight pressure system.

[4.2.4-2] Thermal effects shall be based on temperature extremes that simulate those predicted for the operating environment plus a design margin as specified in Reference 10.

4.2.5 Stress Analysis

[4.2.5-1] A detailed and comprehensive stress analysis of each pressurized system design shall be conducted to verify the hardware strength and stiffness, with the assumption that no crack-like flaws exist in the hardware.

[4.2.5-2] The mounting and arranging of all components in the pressurized system and their effect at interfaces between components and at mounting brackets when subjected to the combined effects from limit loads, MEOP, and deflections of the supporting structures shall be included in the stress analysis.

[4.2.5-3] The analysis shall determine stresses resulting from the combined effects of internal pressure, ground or flight loads, temperatures, and thermal gradients.

[4.2.5-4] Both membrane stress and bending stress resulting from internal pressure and external loads shall be calculated as appropriate to account for the effects of geometrical discontinuities, design configuration, and structural support attachments.

[4.2.5-5] The analysis shall include the effects of adding stresses from restraints, torque forces induced in flexible connections, manufacturing tolerances, test conditions, residual stresses, and assembly stresses.

[4.2.5-6] Thermal effects, including heating rates, temperatures, thermal gradients, thermal stresses and deformations, and changes in the physical and mechanical properties of the materials due to environmental factors, shall be considered in the stress analysis.

[4.2.5-7] Loads shall be combined by using the appropriate design safety factors on the individual load and the results shall be compared to allowable loads. The appropriate design safety factors are given in References 7 and 8. Adjustments to the appropriate design safety factors for pressure components under peak transient pressure conditions are given in Section 4.1.1 ([4.1.1-8] and [4.1.1-9]).

[4.2.5-8] Design safety factors on external (support) loads shall be as assigned to the primary structure(s) supporting the pressurized system.

[4.2.5-9] The effects of flexure of lines, pressure vessels, and supporting structures being acted on by the loads, pressures, and environments shall be accounted for in the analysis.

[4.2.5-10] Classical solutions, finite element methods, or other proven equivalent structural analysis techniques shall be used to calculate the stresses, strains, and displacements.

[4.2.5-11] Minimum material gauges as specified in the design drawing shall be used in the stress analysis.

[4.2.5-12] The allowable material strength shall reflect the effects of temperature, thermal cycling and gradients, processing variables, and time associated with the design environments.

[4.2.5-13] The effect of thickness gradients and variations in material thickness and manufacturing-process parameters, as specified in the design documentation, shall be used in the stress analysis.

[4.2.5-14] Variations in manufacturing and other design tolerances shall be accounted for.

[4.2.5-15] Evaluation of buckling strength shall consider the combined action of primary and secondary stresses and their effects on general instability, local or panel instability, and crippling.

[4.2.5-16] Minimum margin of safety associated with the parent materials, weldments and heat-affected zones shall be calculated and tabulated for all critical locations of the pressurized system along with their stress levels.

[4.2.5-17] The margin of safety shall be positive against the strength and stiffness requirements of Section 4.2.2 and 4.2.3, respectively.

[4.2.5-18] Records of the stress analysis shall be maintained.

[4.2.5-19] The records shall include the input parameters, data, assumptions, rationales, methods, references, and summary of significant analysis results.

[4.2.5-20] The analysis shall be revised and updated to maintain currency for the life of the program.

4.2.6 Fatigue Analysis

[4.2.6-1] In addition to the stress analysis, conventional fatigue-life analysis shall be performed, as appropriate, on the unflawed pressurized system.

[4.2.6-2] Nominal values of fatigue-life (S-N) data shall be taken from reliable sources such as Reference 11 and 12, or other sources approved by the procuring agency.

[4.2.6-3] A scatter factor of four (4) shall be applied to the service life.

[4.2.6-4] The limit for accumulated fatigue damage using Miner's Rule shall be 80% of the normal limit, i.e., $\Sigma n/N \leq 0.8$.

4.3 Material Requirements

4.3.1 Metallic Materials

[4.3.1-1] Metallic materials used in the assembly and installation of a specific pressurized system shall be selected, evaluated, and characterized to ensure all system requirements are met.

4.3.1.1 Metallic Material Selection

[4.3.1.1-1] Metallic materials shall be selected on the basis of proven environmental compatibility, material strength, and fatigue characteristics.

[4.3.1.1-2] Unless otherwise specified, the material's A-basis allowable shall be used in any application where failure of a single load path would result in loss of structural integrity to any part of the pressurized system.

[4.3.1.1-3] For applications where failure of a redundant load path would result in a safe redistribution of applied loads to other load carrying members, the material's B-basis allowable may be used.

4.3.1.2 Metallic Material Evaluation

[4.3.1.2-1] The selected metallic materials shall be evaluated with respect to material processing, fabrication methods, manufacturing operations, refurbishment procedures and processes, and other factors that affect the resulting strength and fracture properties of the material in the fabricated as well as the refurbished configurations.

[4.3.1.2-2] The evaluation shall ascertain that the mechanical properties, strengths, fatigue, and fracture properties used in design and analyses will be realized in the actual hardware and that these properties are compatible with the fluid contents and the expected operating environments.

[4.3.1.2-3] Materials which are susceptible to stress-corrosion cracking or hydrogen embrittlement shall be evaluated by performing sustained-load fracture tests when applicable data are not available.

4.3.1.3 Metallic Material Characterization

[4.3.1.3-1] The allowable mechanical, fatigue, and fracture properties of all selected metallic materials shall be obtained from reliable sources such as Reference 11, and other sources approved by the procuring agency.

[4.3.1.3-2] Where material properties are not available, they shall be determined by test methods approved by the procuring agency.

4.3.2 Composite Materials

4.3.2.1 Composite Material Selection

[4.3.2.1-1] Composite materials used for a part in a specific pressurized system shall be selected on the basis of environmental compatibility, material strength/modulus, and stress-rupture properties.

[4.3.2.1-2] The effects of fabrication process, temperature/humidity, load spectra, and other conditions, that may affect the strength and stiffness of the material in the fabricated configuration, shall also be included in the rationale for selecting the composite materials.

4.3.2.2 Composite Material Evaluation

[4.3.2.2-1] The materials selected for a composite part shall be evaluated with respect to the material processing, fabrication methods, manufacturing operations and processes, operating environments, service life and other pertinent factors that affect the resulting strength and stiffness properties of the material in the fabricated configurations.

4.3.2.3 Composite Material Characterization

[4.3.2.3-1] The properties of the composite materials selected shall be characterized in their expected operating environments.

[4.3.2.3-2] The properties of all selected composite materials shall be obtained from reliable sources such as Reference 13.

[4.3.2.3-3] Where material properties are not available, they shall be determined by test methods approved by the procuring agency.

4.3.3 Polymeric Materials

4.3.3.1 Polymer Material Selection

[4.3.3.1-1] Polymeric materials used for a part or for joining parts in the pressurized system shall be selected on the basis of environmental compatibility, material strength/modulus, fatigue, creep deformation/relaxation, stress-rupture properties, and suitability as an adhesive, as dictated by the application.

[4.3.3.1-2] The effects of fabrication process, temperature/humidity, load spectra, and other conditions that may affect the strength, stiffness, and dimensional tolerance of the material in the fabricated configuration shall also be included in the rationale for selecting the polymeric materials.

4.3.3.2 Polymer Material Evaluation

[4.3.3.2-1] The materials selected for a polymeric part in the pressurized system shall be evaluated with respect to the material processing, manufacturing operations and processes, operating environments, service life, and other pertinent factors that affect the resulting strength, stiffness, and dimensional tolerance properties of the material in the fabricated configurations.

4.3.3.3 Polymer Material Characterization

[4.3.3.3-1] The properties of the polymeric materials selected shall be characterized in their expected configurations and operating environments.

[4.3.3.3-2] Test methods employing samples representative of the manufacturing processes involved in a specific pressurized system hardware fabrication shall be employed for determining material properties, as required.

[4.3.3.3-3] The test specimens and procedures utilized shall follow standardized test methods (such as those published by ASTM) whenever available in order to provide valid test data for the intended application.

[4.3.3.3-4] A polymeric material’s strength allowable shall be determined from testing of coupon, subscale or full-scale composite parts.

[4.3.3.3-5] When subscale and coupon data are used in the database, correlation between coupon/subscale data and full-scale data shall be established.

[4.3.3.3-6] Degradation of polymer material properties in the presence of pressure system fluids shall be determined in the material characterization and considered in the system analyses of Section 4.2.

[4.3.3.3-7] Particular consideration shall be given to potential for volumetric growth (swell) and softening of materials and their effect on the system.

4.4 Fabrication and Process Control Requirements

[4.4-1] Proven processes and procedures for fabrication and repair shall be used to preclude damage or material degradation during material processing, manufacturing operations, and refurbishment.

[4.4-2] In particular, special attention shall be given to ascertain that the melting, welding, bonding, forming, joining, machining, drilling, grinding, repair, etc., processes as applied to joining system

components and hardware and attaching hardware are within the state-of-the-art and have been used on similar hardware.

[4.4-3] The mechanical and physical properties of the parent materials, weld-joints and heat-affected zones shall be within established design limits after exposure to the intended fabrication processes.

[4.4-4] The machining, forming, joining, welding, dimensional stability during thermal treatments, and through-thickness hardening characteristics of the material shall be compatible with the fabrication processes to be encountered.

[4.4-5] Special precautions shall be exercised throughout the manufacturing operations to guard against processing damage or other structural degradation.

[4.4-6] Bonding, clamping, and joining at the interfaces and mountings of the flight pressure systems shall all be controlled to ensure that all requirements are met.

4.5 Contamination Control and Cleanliness Requirements

Contamination includes solid, liquid, and gaseous material unintentionally introduced into the system.

4.5.1 Design for Contamination Control

[4.5.1-1] An analysis shall be conducted to determine the sensitivity of the system and all its components to contamination levels to include both particulate and non-volatile residue (NVR).

[4.5.1-2] Cleanliness requirements for the system and each component shall be based on the contamination analysis and applied during assembly, integration, test, and final operations.

[4.5.1-3] Filters shall be placed in the system to protect sensitive components including pressure regulators, valves, orifices, injectors, and sealing surfaces.

4.5.2 Filter Design Requirements

[4.5.2-1] The filter rating shall be based on the components' sensitivity.

[4.5.2-2] Filter capacity shall be determined based on the following aspects:

a) The cleanliness specifications of pressure vessels, components, and lines, and;
b) the filtration level of fluids used in the system, and;
c) an allocation for contamination introduced during manufacturing assembly.

4.5.3 Cleanliness Testing

[4.5.3-1] Cleanliness verification tests shall use flight or flight-representative fluids. Gas is not an appropriate medium for verifying particle count in a liquid system.

[4.5.3-2] The minimum flow rate of fluids during unit cleanliness verification tests shall match the maximum flow rate used across component and system-level testing and in flight operations. Higher level assembly cleanliness verification should use these flow rate conditions to the maximum extent practicable.

[4.5.3-3] Cleanliness verification shall include checks for particulate and NVR.

4.5.4 Foreign Object Debris Prevention

[4.5.4-1] Clean room practices and training shall be established and followed for all areas where manufacturing, integration, and test occur.

[4.5.4-2] After cleanliness verification, unsealed components or subassemblies shall be handled, transported, and stored with positive contamination controls such as end-caps and/or double bagging.

[4.5.4-3] All tools and tooling aids used in the assembly process shall be inventoried with all tools/aids/hardware independently accounted for prior to the next level of assembly or integration.

4.6 Quality Assurance Program Requirements

[4.6-1] The quality assurance program, governed by Reference 14, Reference 15, or their equivalent, shall include those attributes necessary to ensure that the completed flight pressure systems meets its specified requirements. These attributes include (a) verification that materials, parts, subassemblies, assemblies, and all completed and refurbished hardware conform to applicable drawings and process specifications; (b) verification means to ensure that no damage or degradation has occurred during material processing, fabrication, inspection, acceptance testing, shipping, storage, operational use and refurbishment; and (c) process controls that ensure that defects that could cause failure are detected, evaluated, and corrected.

4.6.1 Inspection Requirements

[4.6.1-1] An inspection plan, which may consist of a set of plans, shall be established prior to start of system assembly and installation.

[4.6.1-2] The plan shall specify appropriate inspection points and inspection techniques for use throughout the program, beginning with material procurement and continuing through fabrication, assembly, acceptance test, operation, and refurbishment, as appropriate.

[4.6.1-3] In establishing inspection points and inspection techniques, consideration shall be given to the material characteristics, fabrication processes, design concepts, and structural configuration.

[4.6.1-4] Acceptance and rejection criteria shall be established as part of the plan for each phase of inspection and for each type of inspection.

Inspection techniques and data requirements are contained within References 7 and 8 for all pressure hardware. The sum of these satisfies system requirements.

4.7 Test Requirements

References 7 and 8 control the internal and external qualification pressure testing conducted on all pressure vessels, pressurized structures, and pressure components to demonstrate no failure at the design burst pressure. Other environmental qualification tests are controlled by Reference 10 or similar. Qualification testing is not required for lines and fittings that are fabricated using common aerospace materials and manufacturing processes.

[4.7-1] All flight pressurized systems shall pass acceptance testing to include a proof pressure test, a leak test at MEOP, and functional testing in that order as well as a bonding and grounding test prior to first use. Note that functional testing may precede proof testing within a particular system test series as long as functional testing is conducted at some time after the proof test.

[4.7-2] Functional tests, leak tests, and bonding and grounding tests shall be conducted after arrival at the launch processing facility. Systems that are filled and pressurized to flight levels prior to arrival at the launch facility are not required to repeat leak, functional, bonding and/or grounding tests.

4.7.1 Proof-Pressure Test Requirements

[4.7.1-1] For systems with zones operating at different pressures, each zone shall be tested to its proof pressure level. The proof pressure level will be limited by the component with the lowest proof factor within that zone.

[4.7.1-2] Proof pressure testing shall demonstrate that the flight pressure system will sustain proof pressure without distortion, damage, leakage, or loss of functionality.

[4.7.1-3] Zones that include relief valves and/or burst disks shall be proof tested without the relief valves and/or burst disks. The interface connections to the relief valves and/or burst disks will not be proof tested but should undergo NDI capable of detecting detrimental flaws.

The minimum proof factor and the corresponding design burst factor for tests of typical pressure vessels, pressurized structures and pressure components (including lines and fittings, fluid return sections, fluid return hoses) are provided in References 7 and 8.

4.7.2 System Leak Test Requirements

The method used to detect and/or measure leakage is purposely left unspecified. The accuracy of the method must be sufficient to verify mission requirements. The highest accuracy test practicable should be utilized. For systems to be filled with a liquid or a hazardous fluid, a suitable leak check gas may be used.

[4.7.2-1] For systems with zones operating at different pressures, each zone shall be at its MEOP for leak tests.

[4.7.2-2] The leak test shall either:

a) use the same fluid in the leak test as the system operating fluid or
b) use conservative leakage flow correlations between the leak test fluid and the system operating fluid to restrict the allowed leak rate.

[4.7.2-3] All mechanical connections, gasket joints, seals, weld seams, and other items susceptible to leakage shall be tested.

[4.7.2-4] Valve seals, including redundant elements relied upon for fault tolerance, that are susceptible to temperature-related leakage shall be tested at the cold and hot temperature extremes during component-level qualification and acceptance tests.

[4.7.2-5] Internal and external leak rates through valves (including fill and drain valves, thruster valves, pressure relief valves, check valves, and regulators) shall be measured and verified within

specification at the pressurized system level of assembly. Verification at temperature extremes is preferred for those seals that are susceptible to temperature-related leakage. Verification at higher levels of vehicle build are preferred if practicable.

[4.7.2-6] For pressure assisted seals, the leakage rate shall be verified at the minimum predicted operating pressure at the pressurized system level of assembly. Verification at higher levels of vehicle build are preferred if practicable.

4.7.3 System Functional Test Requirements

[4.7.3-1] System functional tests, such as those conducted as part of Specification Performance in Reference 10, shall include flow checks to verify component interactions and the absence of major flow obstructions.

[4.7.3-2] The open/close response of all valves shall be verified as part of system functional tests.

[4.7.3-3] For critical flow control devices such as regulators, specification performance shall be verified as part of system functional tests.

[4.7.3-4] As part of system functional tests, internally redundant elements of flow control devices (including fill and drain valves) shall be independently verified for specification performance when that redundancy is required by the fault tolerance design of the system.

[4.7.3-5] For actively controlled valves, vehicle level tests shall verify end-to-end response to commands.

4.8 Operation and Maintenance Requirements

4.8.1 Operating Procedure

[4.8.1-1] Operating procedures shall be established for the pressurized system.

[4.8.1-2] The procedures shall be compatible with the safety requirements and personnel control requirements at the facility where the operations are conducted.

[4.8.1-3] Step-by-step directions shall be written with sufficient detail to allow a qualified technician or mechanic to accomplish the operations.

[4.8.1-4] Schematics that identify the location and pressure limits of all components and their interconnections into a system shall be included in the procedure or be made available at the time it is run.

[4.8.1-5] Prior to initiating or performing a procedure involving hazardous operations with flight-pressure systems, practice runs shall be conducted on non-pressurized systems until the operating procedures are well rehearsed.

[4.8.1-6] Initial tests shall then be conducted at pressure levels not to exceed 50 percent of the normal operating pressures until operating characteristics can be established and stabilized.

[4.8.1-7] Only qualified and trained personnel shall be assigned to work on or with high pressure systems.

[4.8.1-8] Warning signs identifying the hazards shall be posted at the operations facility prior to pressurization.

4.8.2 Inspection and Maintenance

[4.8.2-1] The results of the stress analysis and the fatigue-life analysis shall be used in conjunction with the appropriate results from the structural development and qualification tests to develop a quantitative approach to inspection and repair.

[4.8.2-2] The allowable damage limits for each component of the flight pressure system shall be used to establish the required inspection interval and repair schedule to maintain the hardware to the requirements of this document.

[4.8.2-3] Procedures shall be established for recording, tracking, and analyzing operational data as it is accumulated to identify critical areas requiring corrective actions.

[4.8.2-4] Analyses shall include prediction of remaining life and reassessment of required inspection intervals.

4.8.3 Repair and Refurbishment

[4.8.3-1] When tests/inspections reveal defects exceeding permissible levels, the discrepant hardware shall be repaired, refurbished, or replaced, as appropriate.

[4.8.3-2] All repaired or refurbished flight pressure systems shall be recertified after each repair and refurbishment to verify their structural integrity and to establish their suitability for continued service.

4.8.4 Storage

[4.8.4-1] A flight pressure system put into storage shall be protected against exposure to adverse environments that could cause corrosion or other forms of material degradation.

[4.8.4-2] A flight pressure system shall be protected against mechanical degradation resulting from scratches, dents, or accidental dropping of the hardware.

[4.8.4-3] Induced stresses due to storage fixture constraints shall be minimized by suitable storage fixture design.

[4.8.4-4] In the event storage requirements are violated, recertification shall be required prior to return to use.

4.8.5 Documentation

[4.8.5-1] Inspection, maintenance, and operation records shall be kept and maintained throughout the life of the flight pressure system.

[4.8.5-2] As a minimum, the records shall contain the following information:

a) Temperature, pressurization history, and pressurizing fluid for both tests and operations. Temperature and pressures may be expressed as an allowed range in which the system was maintained.

b) Numbers of pressurizations experienced as well as number allowed in damage-tolerance (safe-life) analysis.

c) Results of any inspection conducted, including: inspector, inspection dates, inspection techniques employed, location and character of defects, defect origin and cause. This includes inspections made during fabrication.

d) Storage condition.

e) Maintenance and corrective actions performed from manufacturing to operational use, including refurbishment.

f) Sketches and photographs to show areas of structural damage and extent of repairs.

g) Acceptance and recertification test performed, including test conditions and results.

h) Analyses supporting the repair or modification that may influence future use capability.

4.8.6 Reactivation

[4.8.6-1] A flight pressure system reactivated for use after a period in either an unknown, unprotected, or unregulated ground storage environment shall be recertified to ascertain its structural integrity, functionality, and suitability for continued service before first use.

4.8.7 Recertification

The following requirements pertain to recertification of a flight pressure system prior to return to service.

[4.8.7-1] The documentation of affected components or portions of the flight pressure system shall be reviewed to establish the last known condition.

[4.8.7-2] The pressure system shall be inspected and subjected to appropriate NDI.

[4.8.7-3] The pressure system shall pass all the acceptance test requirements for a new system in accordance with Section 4.7.

4.8.7.1 Test after Limited Modification and Repair

[4.7.7.1-1] If any system element such as valves, regulators, gauges, or tubing has been disconnected or reconnected for any reason, the affected system or subsystem shall be leak tested.

[4.7.7.1-2] For more extensive modification or repair that may affect its ability to meet the requirements of this document or its required functions, the flight pressurized system shall meet the full recertification requirements.

5. Specific System Requirements

This section presents specific design requirements that are, effectively, corrective actions to past issues.

5.1 Design Features

Design components so that, during the assembly of parts, sufficient clearance exists to permit assembly of the components without damage to the O-rings or backup rings where they pass threaded parts or sharp corners.

5.1.1 Routing

[5.1.1-1] Where straight runs are used between two rigid connection points, provision shall be made for expansion joints, motion of the units, or similar compensation to ensure that no excessive strains are applied to the tubing and fittings. Line bends may be used to ease stresses induced in tubing by alignment tolerance and vibration.

[5.1.1-2] Flexhoses, meaning any flexible connector type, shall be used between any two connections where relative motion can be expected to fatigue metal tubes or pipes.

[5.1.1-3] Flexhose installation shall be designed to avoid abrasive contact with adjacent structure or moving parts.

[5.1.1-4] Rigid supports shall not be used on flexhoses.

5.1.2 Grounding

[5.1.2-1] System components and lines shall be electrically grounded to metallic structures.

5.1.3 Ground Handling

[5.1.3-1] Fixtures for safe handling and hoisting with coordinated attachment points in the system structure shall be provided.

[5.1.3-2] Handling and hoisting loads shall be in accordance with Reference 5.

5.1.4 Test Points

[5.1.4-1] Test points shall be provided such that disassembly for test is not required.

[5.1.4-2] The test points shall be easily accessible for attachment of ground test equipment.

5.1.5 Common-Plug Test Connectors

[5.1.5-1] Common-plug test connectors for pressure and return sections shall be designed to require positive removal of the pressure connection prior to unsealing the return connections.

5.1.6 Individual Pressure Test Connectors

[5.1.6-1] Individual pressure test connectors shall be designed to positively prevent inadvertent cross-connections.

5.1.7 Threaded Parts

[5.1.7-1] All threaded parts in components shall be securely locked to resist uncoupling forces by acceptable safe design methods. Safety wiring and self-locking nuts are examples of acceptable safe design.

[5.1.7-2] Torque for threaded parts in components shall be specified.

5.1.8 Internally Threaded Bosses

[5.1.8-1] The design of internally threaded bosses shall preclude the possibility of damage to the component or the boss threads because of screwing universal fittings to excessive depths in the bosses.

5.1.9 Retainer or Snap Rings

[5.1.9-1] Retainer or snap rings shall not be used in a pressurized system where failure of the ring would allow connection failures or blowouts caused by internal pressure.

5.2 Component Selection

In all cases, flareless tube fittings must be properly preset prior to pressure applications.

5.2.1 Connections

[5.2.1-1] System connections for incompatible propellants shall be keyed, sized, or located so that it is physically impossible to interconnect them.

[5.2.1-2] Pressure components shall be selected to ensure that misconnections or reverse installations within the subsystem are not possible.

[5.2.1-3] Color codes, labels, and/or directional arrows shall be used to identify hazards and direction of flow.

5.2.2 Actuator Pressure Rating

[5.2.2-1] Components shall be specified that are capable of actuation under pressure equal to the MEOP in the circuit in which they are installed.

5.3 Design Pressures

[5.3-1] Actuation of pneumatic systems shall not be adversely affected by any back-pressure resulting from concurrent operations of other parts of the system under service conditions.

5.4 Design Loads

Flexhose installations should be designed such that no stress or strain of any nature in the hard lines or components can be produced. Any such stress or strain as well as the stress induced because of dimensional changes caused by pressure or temperature variations, and torque forces induced in the flexhoses, is to be included in the design requirements analyses of Section 4.2.

5.4.1 Acceleration and Shock Loads

[5.4.1-1] All lines and components shall be installed to withstand all expected acceleration and shock loads. Shock-isolation mounts may be used, if necessary, to eliminate destructive vibration and interference collisions.

5.4.2 Torque Loads

[5.4.2-1] The mounting of components, including valves, shall be on structures having sufficient strength to withstand torque and dynamic loads. Only lightweight components that do not require adjustment after installation may be supported by the tubing, provided that a tube clamp is installed on each tube near the component.

5.4.3 Vibration Loads

[5.4.3-1] Tubing shall be supported by clamps of a suitable design and spacing to restrain destructive vibration loads.

5.5 Electrical

5.5.1 Hazardous Atmospheres

[5.5.1-1] Electric components for use in potentially ignitable atmospheres shall be verified to be incapable of causing an explosion in the intended application.

5.5.2 Solenoid Dielectric Withstanding Voltage

[5.5.2-1] All solenoids shall safely withstand a test voltage of not less than 1500 V rms at 60 cps for 1 minute between terminals and case. See Reference 1 Test Method 301 for additional clarification of this dielectric withstanding voltage test.

[5.5.2-2] The dielectric withstanding voltage test shall occur after a maximum temperature exposure, such as thermal bake-out of the coil and potting compound, to verify no voids or cracked insulation during manufacture.

5.6 Pressure Relief

Pressure relief devices are an acceptable means of providing fault tolerance against over-pressure conditions.

5.6.1 Flow Capacity

[5.6.1-1] All pressure relief devices shall provide relief at full-flow capacity at conditions up to 110% of the MEOP of the system.

5.6.2 Sizing

[5.6.2-1] The size of pressure relief devices shall be specified to withstand maximum pressure and flow capacities of the pressure source, to prevent pressure exceeding 110% of the MEOP of the system.

5.6.3 Negative Pressure Protection

[5.6.3-1] Thin-walled vessels that can collapse by a negative internal pressure during hydrostatic testing or storage and transportation shall have negative pressure relief and/or prevention devices.

5.6.4 Pump Pressure Relief

[5.6.4-1] Hydraulic systems employing power-operated pumps shall include a pressure-regulating device and an independent safety-relief valve.

5.6.5 Thermal Pressure Relief

[5.6.5-1] Thermal-expansion relief valves shall be installed as necessary to prevent system damage from thermal expansion of hydraulic fluid, as in the event of gross overheating. Internal valve leakage is not considered an acceptable method of providing thermal relief.

5.6.6 Pressure Relief Vents

[5.6.6-1] The vents of pressure relief devices shall outlet only to areas of relative safety from fire hazard.

5.7 Hydraulic System Components

5.7.1 Variable Response

[5.7.1-1] Shutoff valves shall not be used in hydraulic systems where the event of force balance on both inlet ports may occur, thus causing the shutoff valve to restrict flow from the outlet port.

5.7.2 Fire Resistant Fluids

[5.7.2-1] Fire resistant or flame proof hydraulic fluid shall be used where the system design can expose hydraulic fluid to potential ignition sources or where the system is adjacent to a potential fire zone and the possibility of flame propagation exists. This requirement does not pertain to propellants, but their usage in hydraulic actuation of other mechanisms must consider protection against inadvertent ignition.

5.7.3 Accumulators

[5.7.3-1] Hydraulic systems incorporating accumulators shall be interlocked to either vent or isolate accumulator fluid pressure when power is shut off.

5.7.4 Lock Valves

[5.7.4-1] When two or more hydraulic actuators are mechanically tied together, only one lock valve shall be used to hydraulically lock all the actuators.

[5.7.4-2] Hydraulic lock valves shall not be used for lockup periods likely to involve extreme temperature changes, unless fluid expansion and contraction effects are accounted for.

5.7.5 Cavitation

5.7.5.1 Inlet Pressure

[5.7.5.1-1] The inlet pressure of hydraulic pumps shall be specified to prevent cavitation effects in the pump passage or outlets.

5.7.5.2 Fluid Column

[5.7.5.2-1] Hydraulic systems shall have positive protections against breaking the fluid column in the suction line during standby.

5.8 Pneumatic System Configuration

[5.8-1] The configuration of pneumatic components shall permit bleeding of entrapped moisture, lubricant, particulate material, or other foreign material hazardous to this system.

6. System Safety Requirements

The following requirements are specific to system safety which is governed by Reference 2. The system safety requirements are based on an approach of acceptable risk which is defined as risk that the appropriate acceptance authority is willing to accept. These requirements are similar to those listed in Reference 6, but distinct in regard to the focus on the vehicle and mission system safety aspects as well as the governing authority.

Acceptance of risk within the following requirements does not take precedence over the requirements listed in Sections 4 and 5. Any apparent conflicts that arise must be adjudicated by tailoring of or waivers to the prior requirements along with completion of the Reference 2 assessment process.

6.1 System Hazard Analysis

[6.1-1] A system hazard analysis shall be performed on all pressurized system hardware, to identify hazards to the system, personnel and facilities.

[6.1-2] All storage, handling, transportation, prelaunch processing, launch, and post-launch operations and conditions shall be included in the analysis.

[6.1-3] A detailed system physical and functional analysis of the pressurized system shall be performed to determine if the components within the pressurized system are capable of supporting all requirements without leading to a catastrophic or critical mishap based on their operation, interaction, environment, and sequence of events.

[6.1-4] The physical and functional analysis shall identify any single malfunction, software error, or personnel error in the operation of any component that may create conditions leading to an unacceptable risk of a mishap.

[6.1-5] The physical and functional analysis shall also evaluate any secondary or subsequent occurrence, failure, component malfunction, or software errors initiated by one or more primary events that could result in a mishap.

[6.1-6] Hazards identified by the analysis that may lead to catastrophic or critical hazards shall be designated as safety-critical.

[6.1-7] Safety-critical items shall require mitigation by one or more of the following, listed in order of decreasing effectiveness:

a) Design modifications to eliminate the hazard.

b) Reduce risk through design alteration.

c) Incorporate engineered features or devices that reduce the severity or the probability of the mishap potential caused by the hazard(s). In general, engineered features actively interrupt the mishap sequence and devices reduce the risk of a mishap.

d) Provide warning devices.

e) Incorporate signage, procedures, training, and personal protective equipment.

6.2 Redundancy

[6.2-1] System analysis data shall show that:

a) In systems where pressure regulator failure involves a safety-critical hazard, regulation is redundant and where passive redundant systems are used includes automatic switchover.

b) When the hazardous effects of safety critical failures or malfunctions are prevented through the use of redundant components or systems, all such redundant components or systems have a high probability of being operational prior to the initiation of irreversible portions of safety critical operations or events.

6.3 Low Safety Factor Relief Requirement

[6.3-1] In the event of launch abort, safety-critical pressure vessels with safety factors less than 2.0 in the design shall provide a means for the automatic relief, depressurization, and pressure verification of the vessels.

6.4 Control Devices

6.4.1 Directional Control Valves

[6.4.1-1] Safety-critical pressure systems shall be designed to incorporate two or more directional control valves to preclude the possibility of inadvertently directing the flow or pressure from one valve into the flow or pressure path intended for another valve, with any combination of valve settings possible in the total system.

6.4.2 Overtravel

[6.4.2-1] Control devices shall be designed to prevent overtravel or undertravel that may contribute to a hazardous condition, or damage to the valve.

6.5 Component Requirements

6.5.1 Cycling

[6.5.1-1] Cycling capability for pressure components as specified in Reference 7 that are safety-critical per Section 6.1 shall be not less than four times the total number of expected cycles, including system tests, but not less than 2000 cycles (including the life factor of four). This cycling verification includes operation over the required temperature range.

6.5.2 Actuators

[6.5.2-1] Safety critical actuators shall have positive mechanical stops at the extremes of safe motion.

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